Balloons in the Sky: Unveiling the Characteristics and Trade-offs of the Google Loon Service

Pablo Serrano, Marco Gramaglia, Francesco Mancini, Luca Chiaraviglio, Giuseppe Bianchi

uc3m | Universidad Carlos III de Madrid

TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

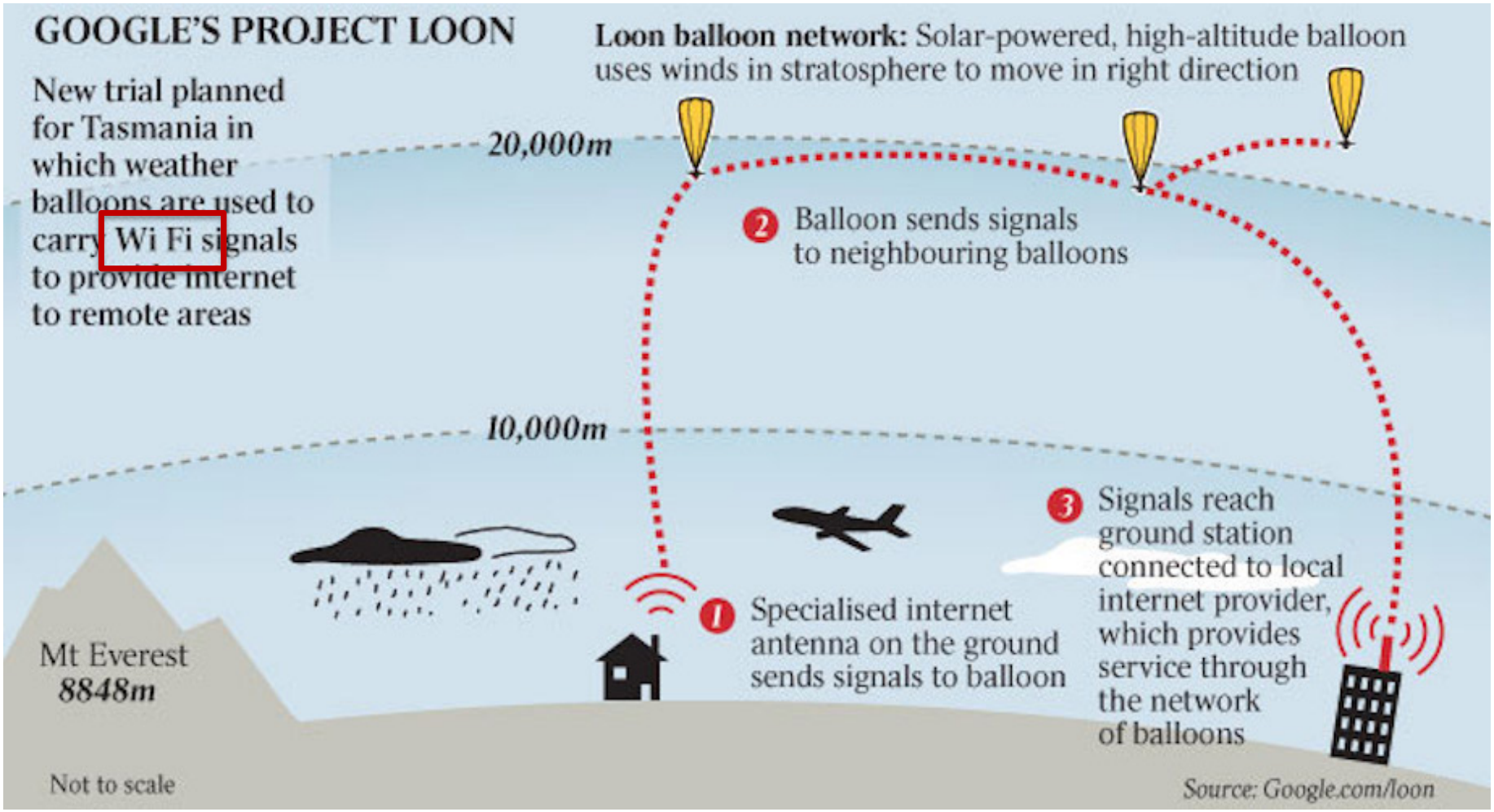
Università degli Studi di Brescia, Dec. 2nd 2022

THE GOOGLE (ALPHABET) LOON PROJECT

Motivation

- Most countries are heading towards the realization of the so-called Gigabit Society,
- But ½ of the population of the planet has no Internet connection
- Many of those live in rural places
  - No cellular towers
  - No (network) infrastructures
  - E.g., archipelagos, jungles, mountains, (low density)

Loon Approach



https://xedknowledge.com/Coverstory_Demo.aspx?id=qJZ85UM6v6RmN6IFBF+t1Q==

Challenges

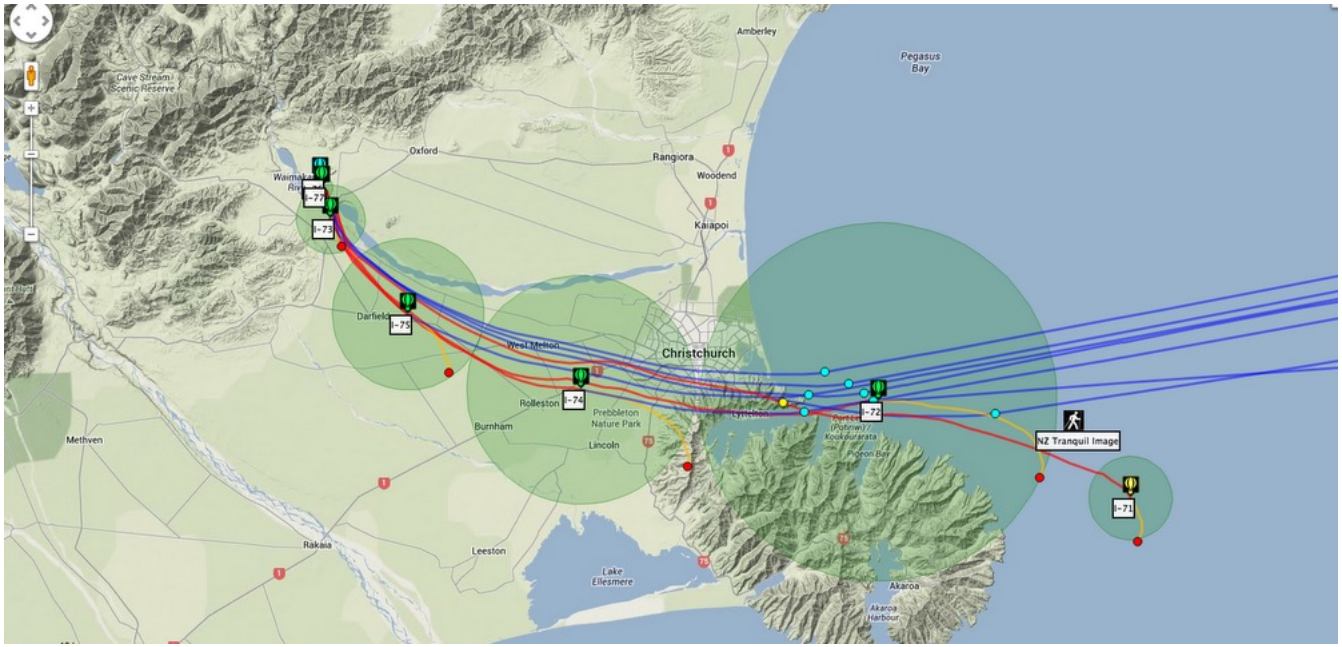
- Just wind and solar power: move the balloons up or down to catch the winds
  - No propulsion engine
- How to manage a fleet of balloons?
  - Complex algorithms and lots of computing power

"The idea may sound a bit crazy, but there's solid science behind it"

https://blog.google/alphabet/introducing-project-loon/

Official Launch

- June 2013: 30 balloons launched to connect 50 receivers



https://blog.google/alphabet/introducing-project-loon/

Launch (New Zealand)

Launch site (Nevada)

https://blog.x.company/loon-draft-c3fcebc11f3f

Some technical details

- Small box: 10 kg
  - Batteries, circuit boards, navigation hw
  - Ubiquiti Networks Rocket M2
- Technology
  - Initially ISM
  - Switched to LTE
- Each balloon: 40 km of coverage radius
- Inter-balloon links: up to 100 km

Our Research Question

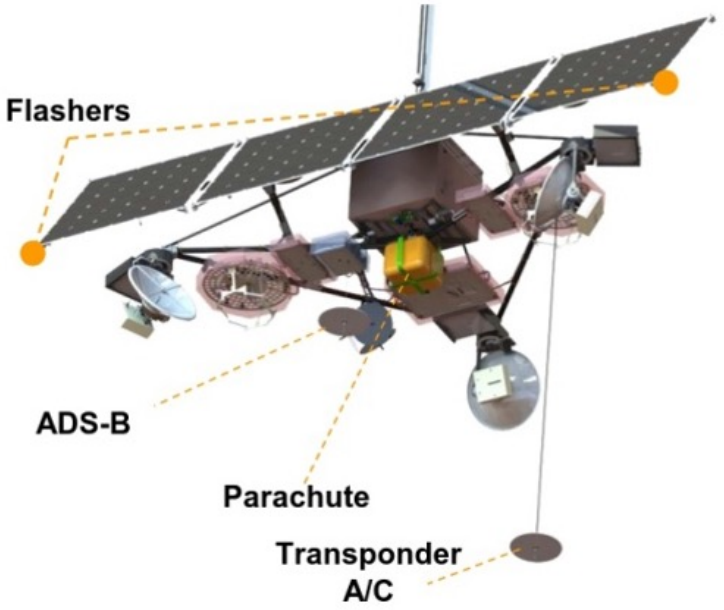
- How *effective* and *stable* can be the service provided by Loon?

- Steps
  1. Gather data
  2. Identify use cases
  3. Derive performance figures: coverage

1) GATHER DATA – TRACKING BALOONS

Tracking balloons

- Automatic Dependent Surveillance–Broadcast (ADS-B) that broadcasts
  - ICAO address
  - Position, speed, altitude
  - Callsign a.k.a. flight number



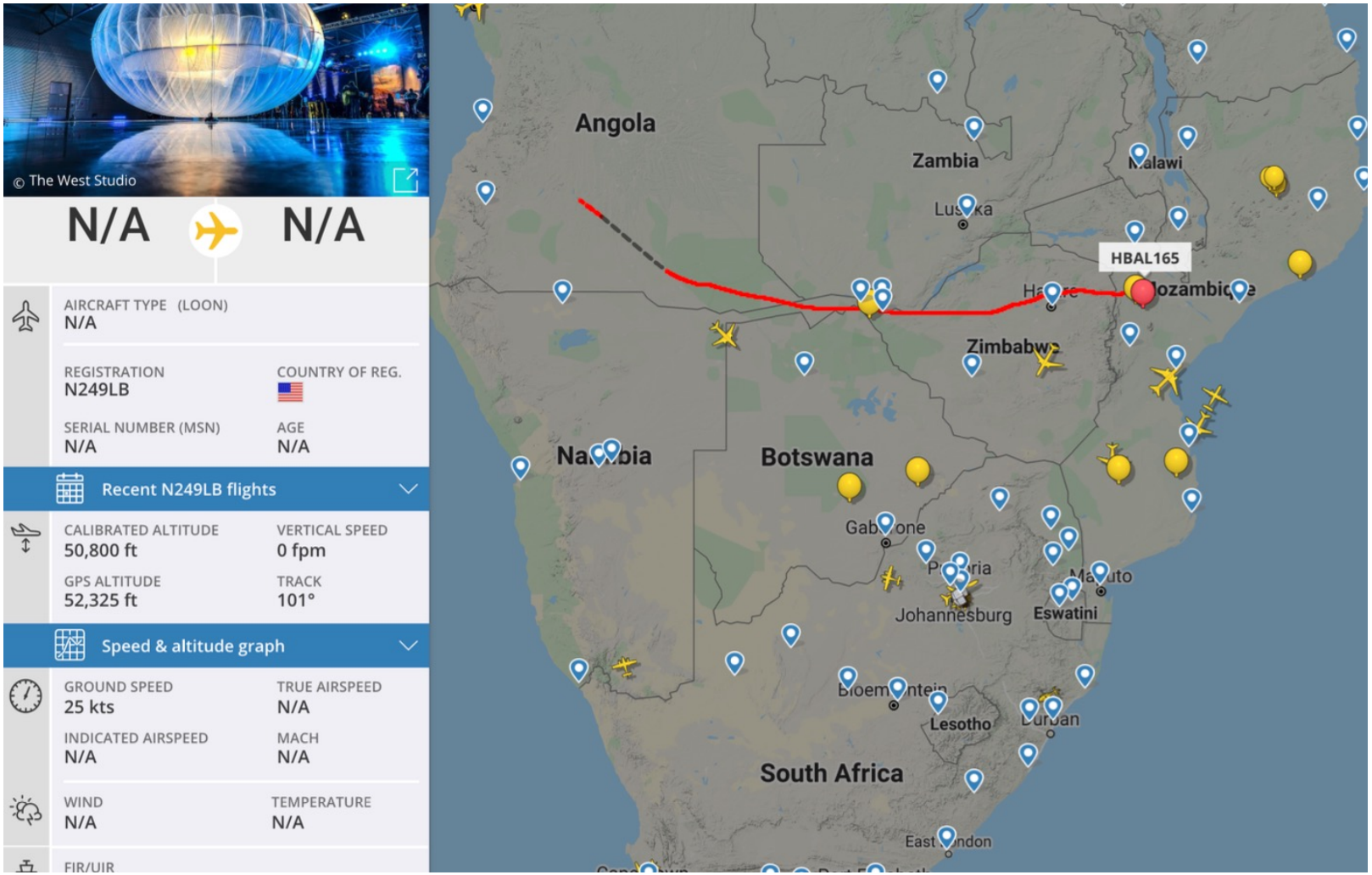
- ADS-B messages can be received with DVB-T USB sticks
- This has fostered a number of crowd-sourced initiatives

AirNav RadarBox
You fly. We track.

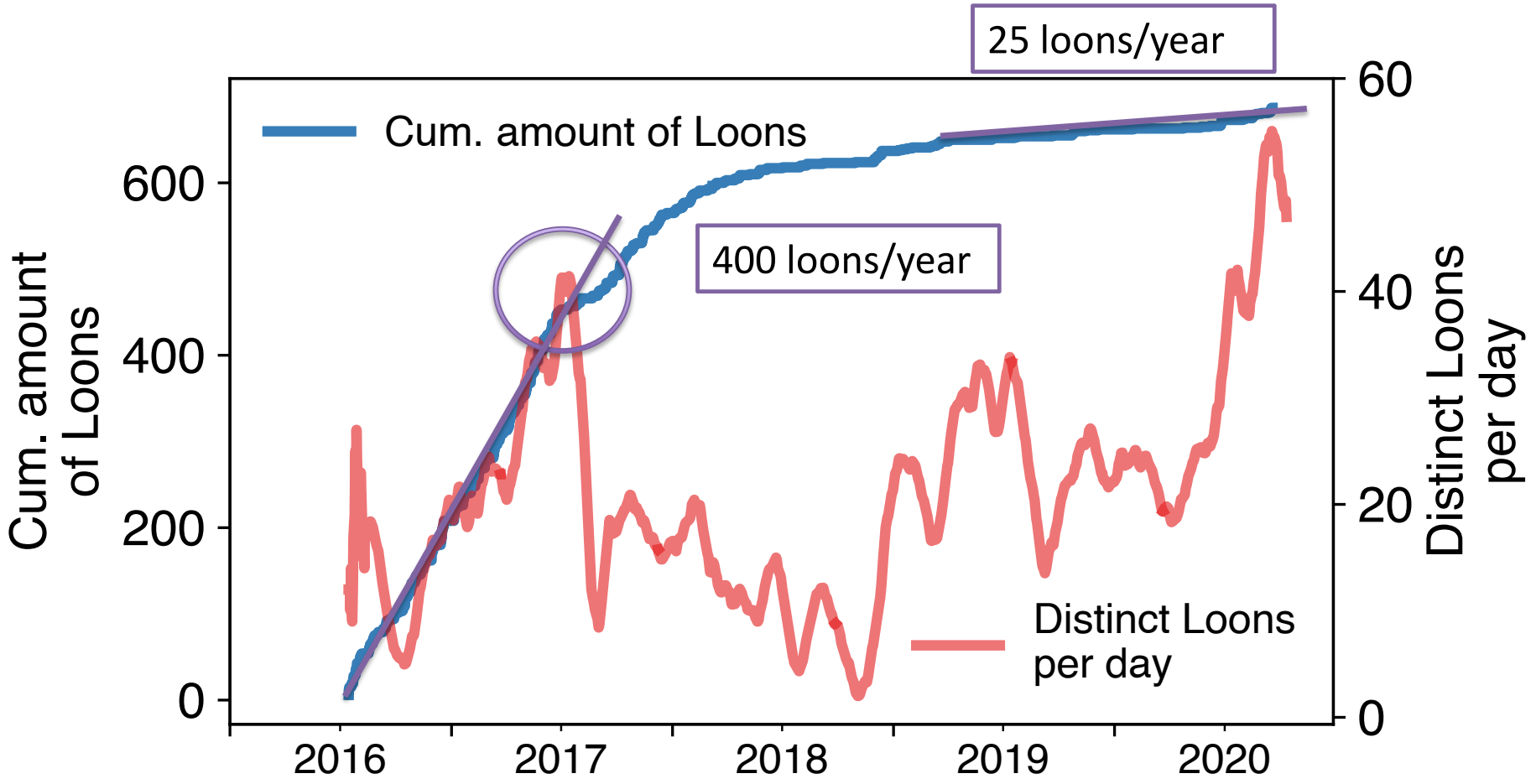
flightradar24
LIVE AIR TRAFFIC

FR24 Business

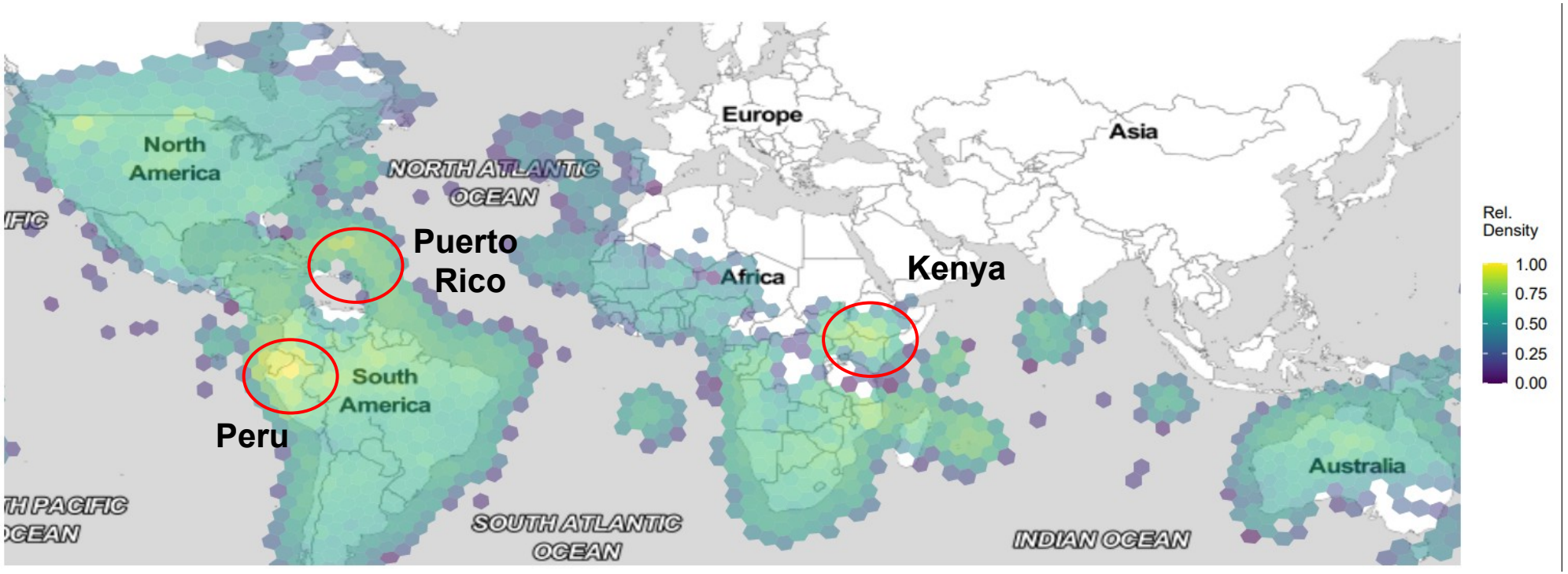
Methodology – Look for HBAL's



Number of Loons over time



Relative loon density



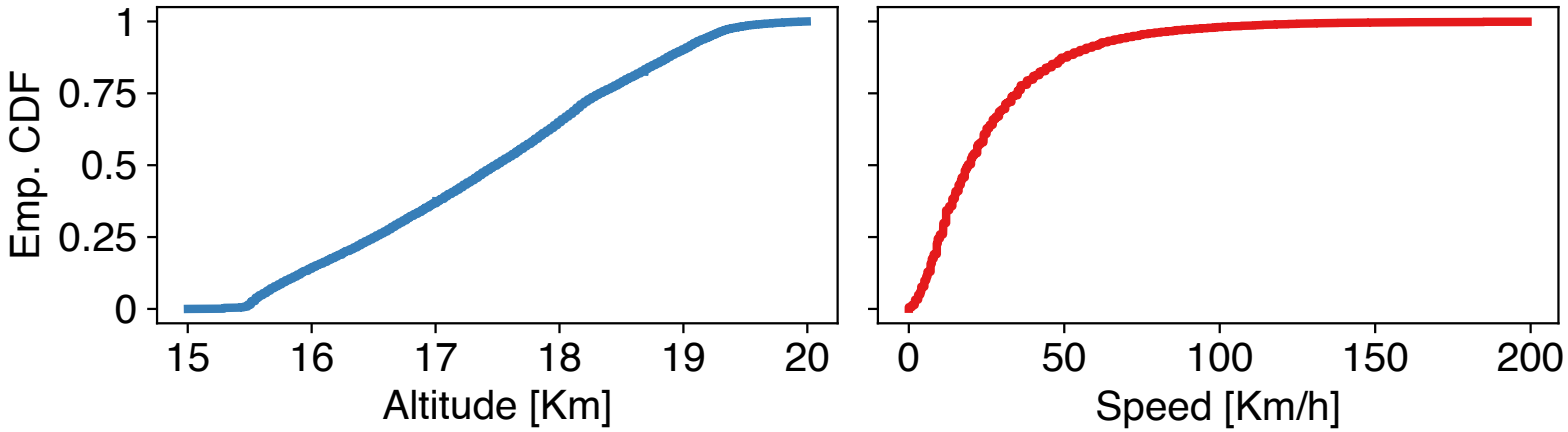
- Deployment time
  - From Ceiba 1) to Perú: approx. 20 h, 2) to Kenya: 5 days

Altitude and Speed

- Stratosphere: between 16 km and 20 km
- According to announcements: low speeds (10--30 km/h) and minimal turbulence

https://xedknowledge.com/Coverstory_Demo.aspx?id=qJZ85UM6v6RmN6IFBF+t1Q==

- According to our data



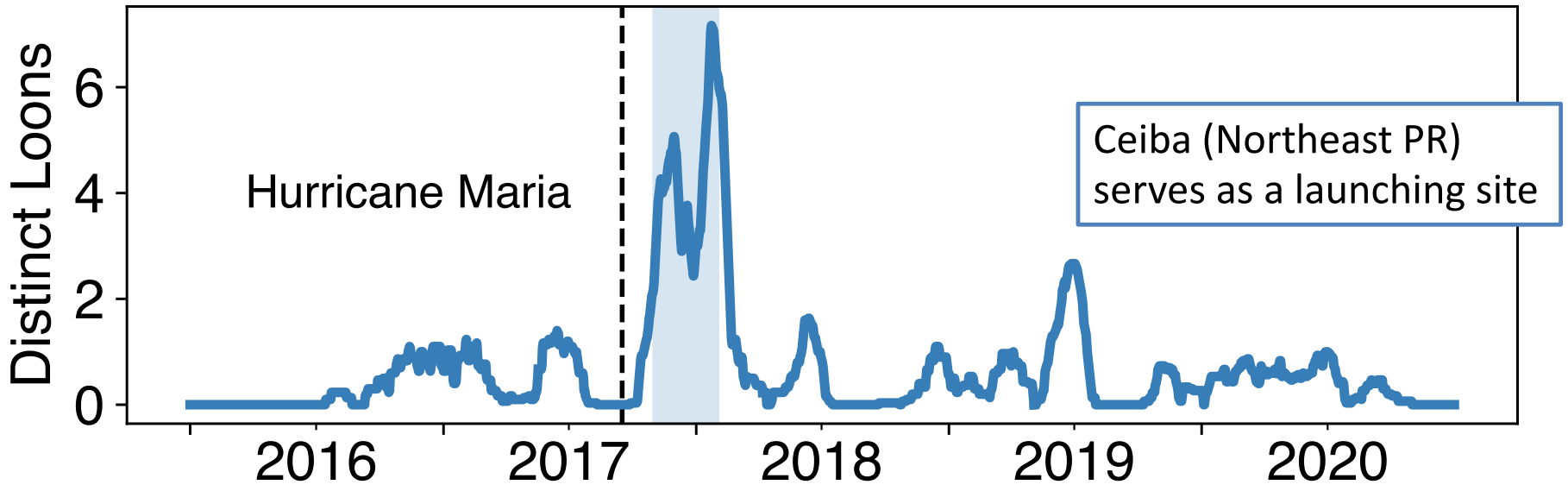
2) IDENTIFY USE CASES

Loon use cases

- There are no official “use cases” or “application scenarios”
- We rely on those that have been extensively covered by media
- We study areas with > 30 days of "minimal coverage” (>2 h/day) for > 3 months

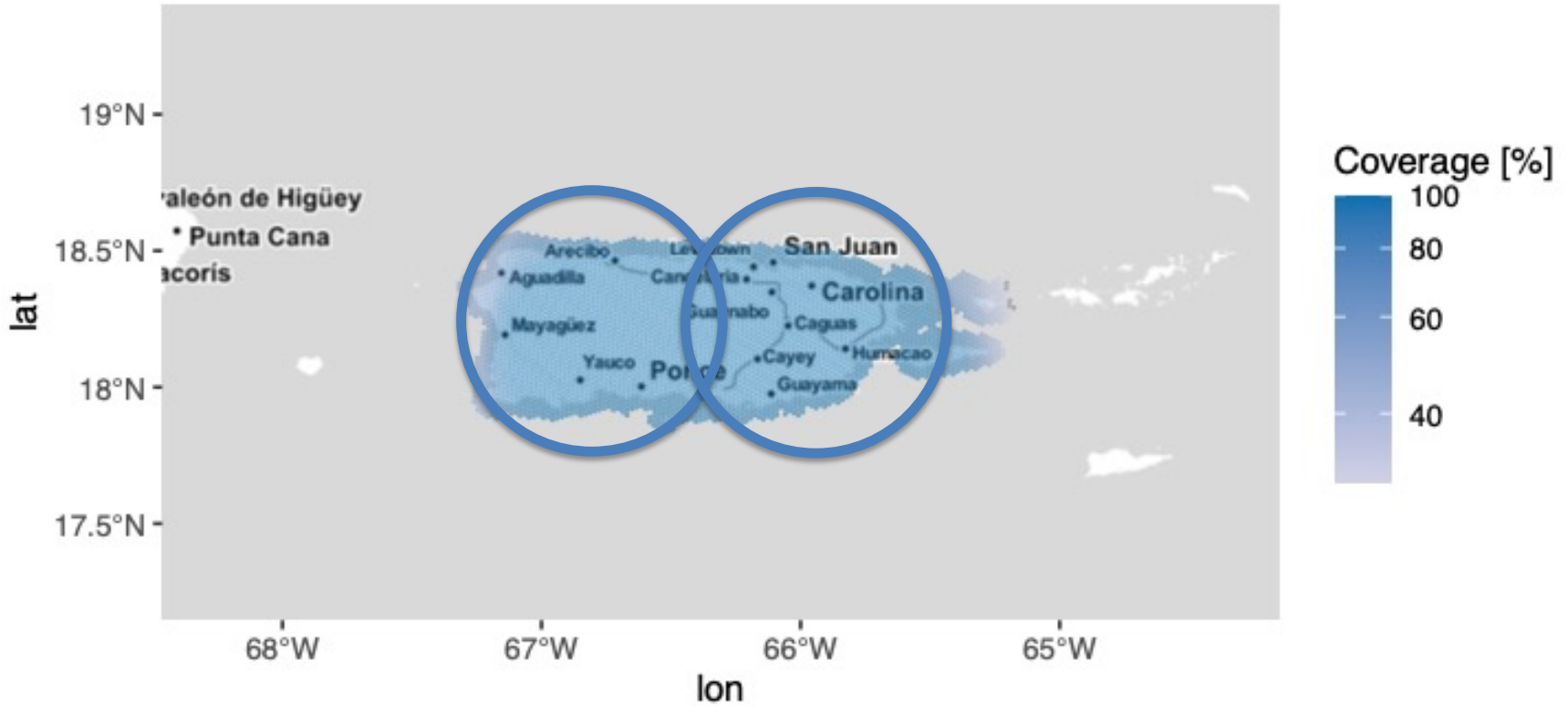
Puerto Rico

- Hurricane Maria: from Sep. 20 until Oct. 2, 2017
- Oct. 6: authorized by the FCC to provide coverage
- Oct. 21: partnership with AT&T and T-Mobile
- Nov. 9: More than 100K people were provided basic connectivity
- Mar 2: service over the island would start to “wind down”



Puerto Rico

- Area: 9 104 km^2 (i.e., approx. 2 Loons)

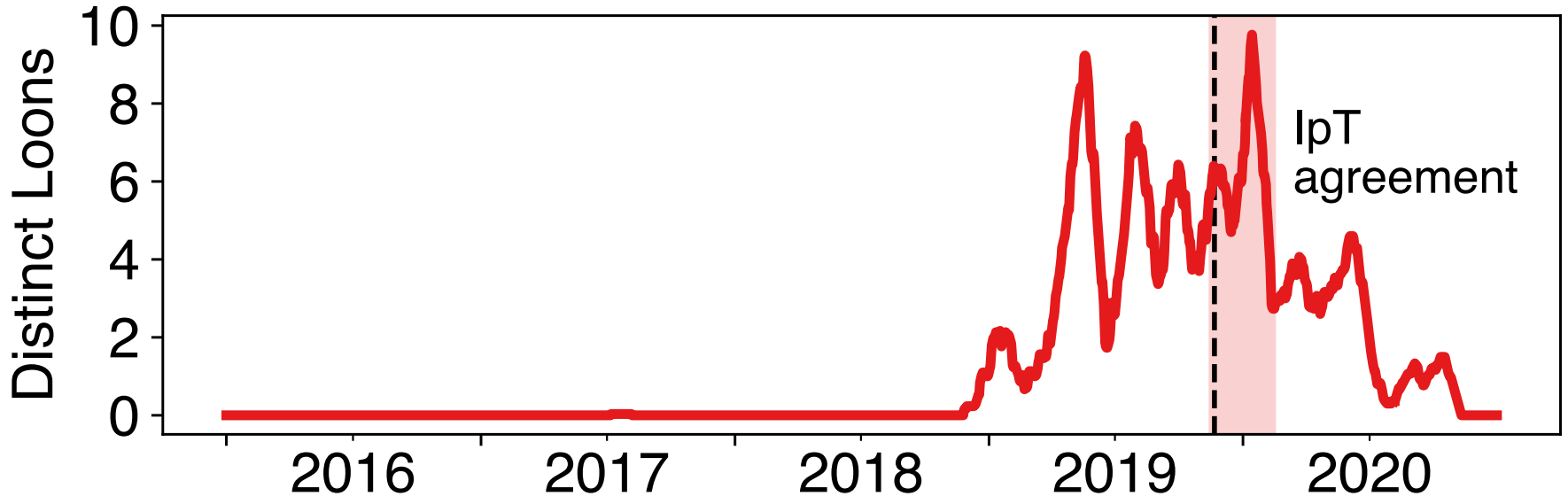


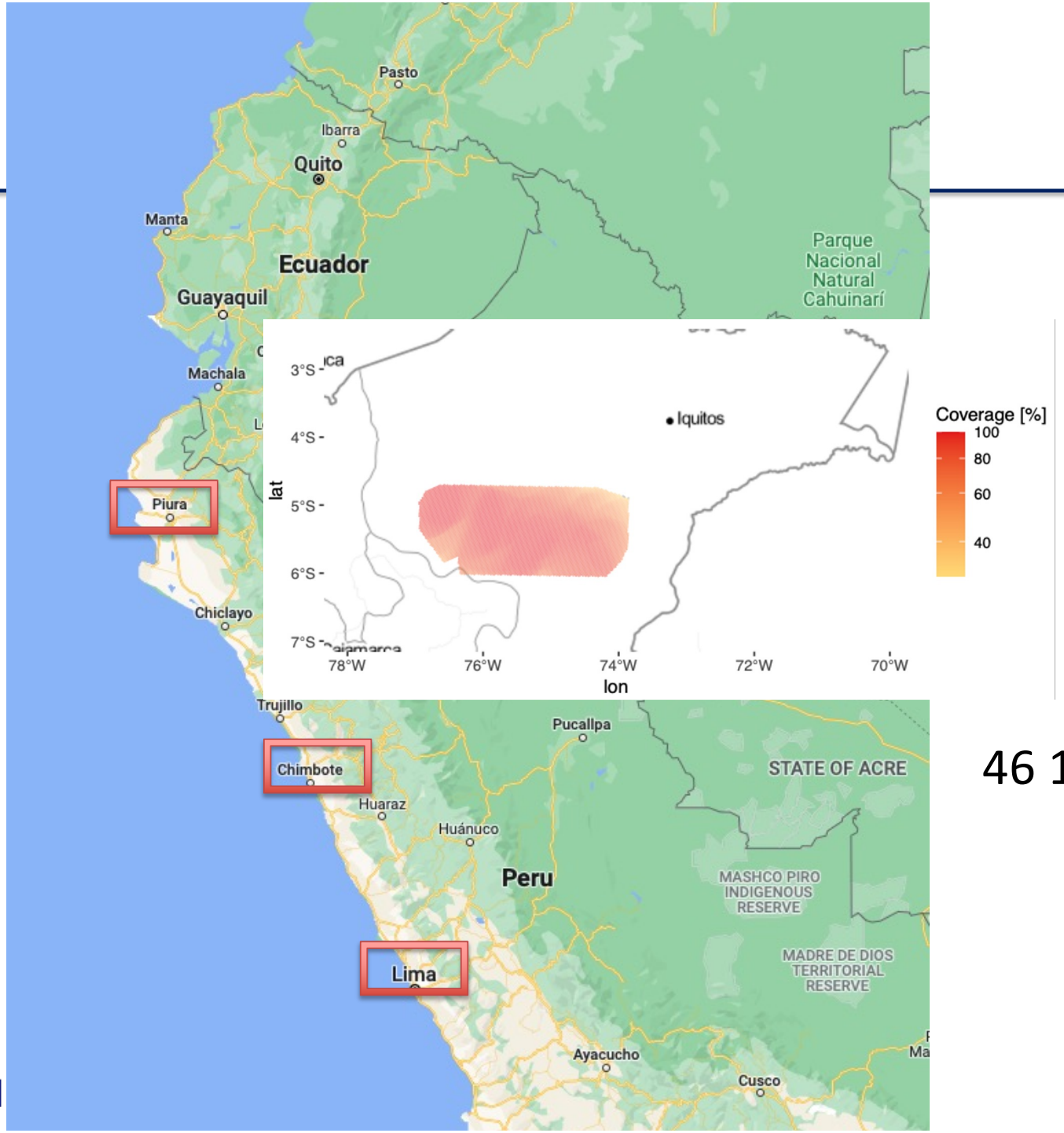
Perú – Loreto region

- 2014: Loon and Telefónica started collaboration
- May 2017: El Niño flooding (Piura, Chimbote, Lima)
- May 2018: 8.0 magnitude earthquake (Acari)

Coast

- Nov. 2019: Service over of the Loreto Region → Amazonas
  - Neutral-host Internet Para Todos (IpT) operator

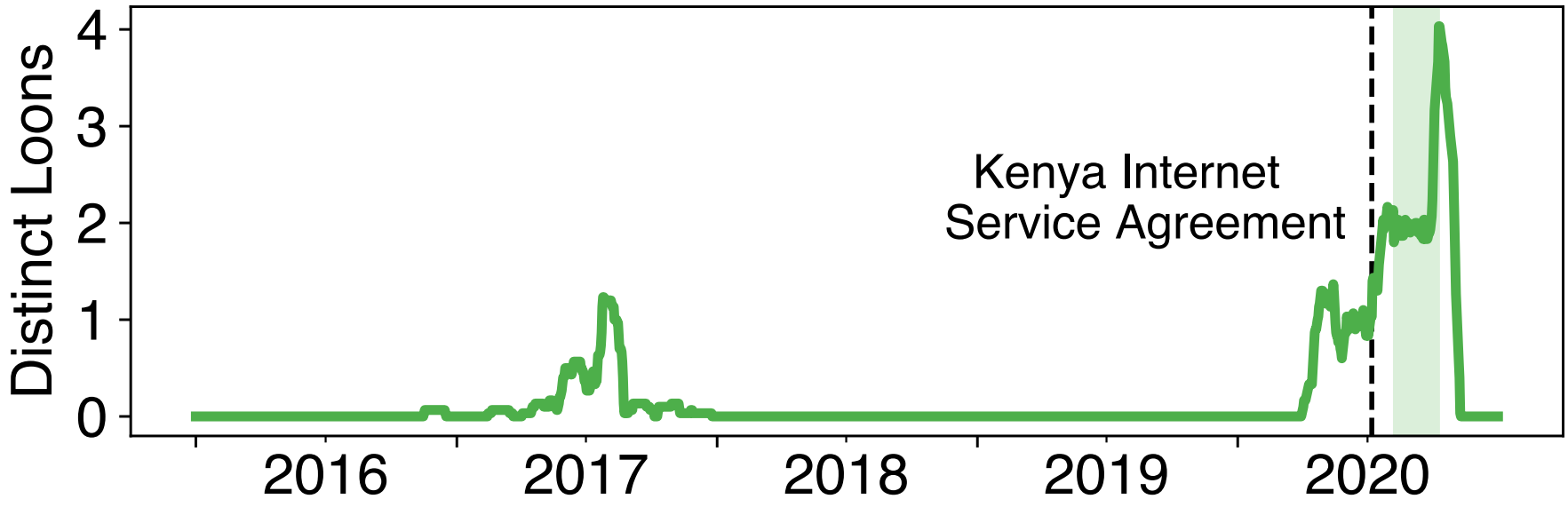



Pasto
Ibarra
Quito
Manta
Ecuador
Guayaquil
Parque Nacional Natural Cahuinarí
Machala
Piura
Chiclayo
Trujillo
Chimbote
Huaraz
Huánuco
Pucallpa
STATE OF ACRE
Peru
MASHCO PIRO INDIGENOUS RESERVE
MADRE DE DIOS TERRITORIAL RESERVE
Lima
Ayacucho
Cusco
Iquitos
3°S
4°S
5°S
6°S
7°S
lat
78°W
76°W
74°W
72°W
70°W
lon
Coverage [%]
100
80
60
40

46 157 km^2

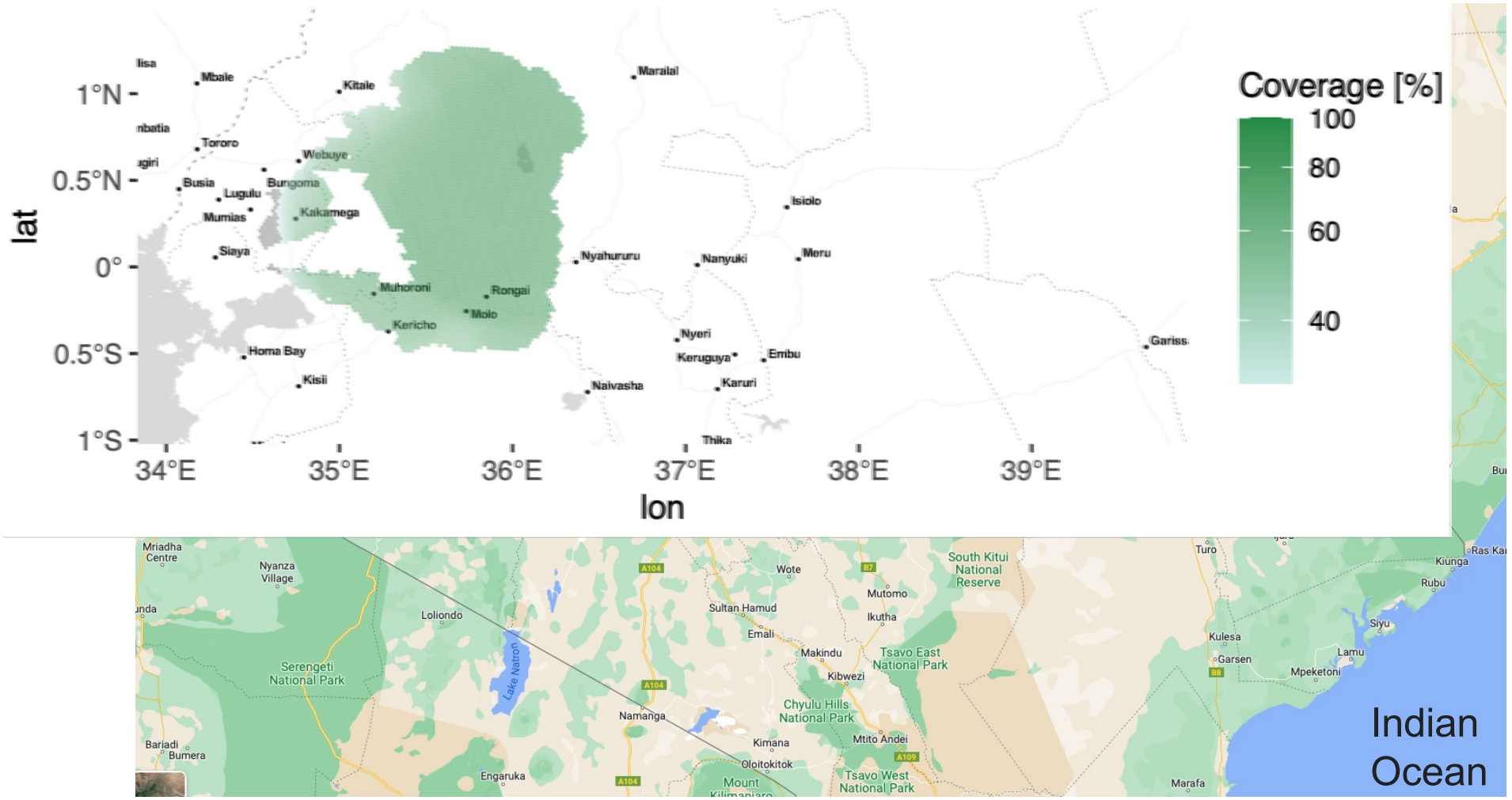
Kenya

- Some activity seems to be taking place back in 2017
- July 2018: the service would start in 2019
- No activity during 2018 and 2019
- March 2020: Kenyan government gave approval
- July 7, 2020: service announcement. Target: 35 loons



Kenya

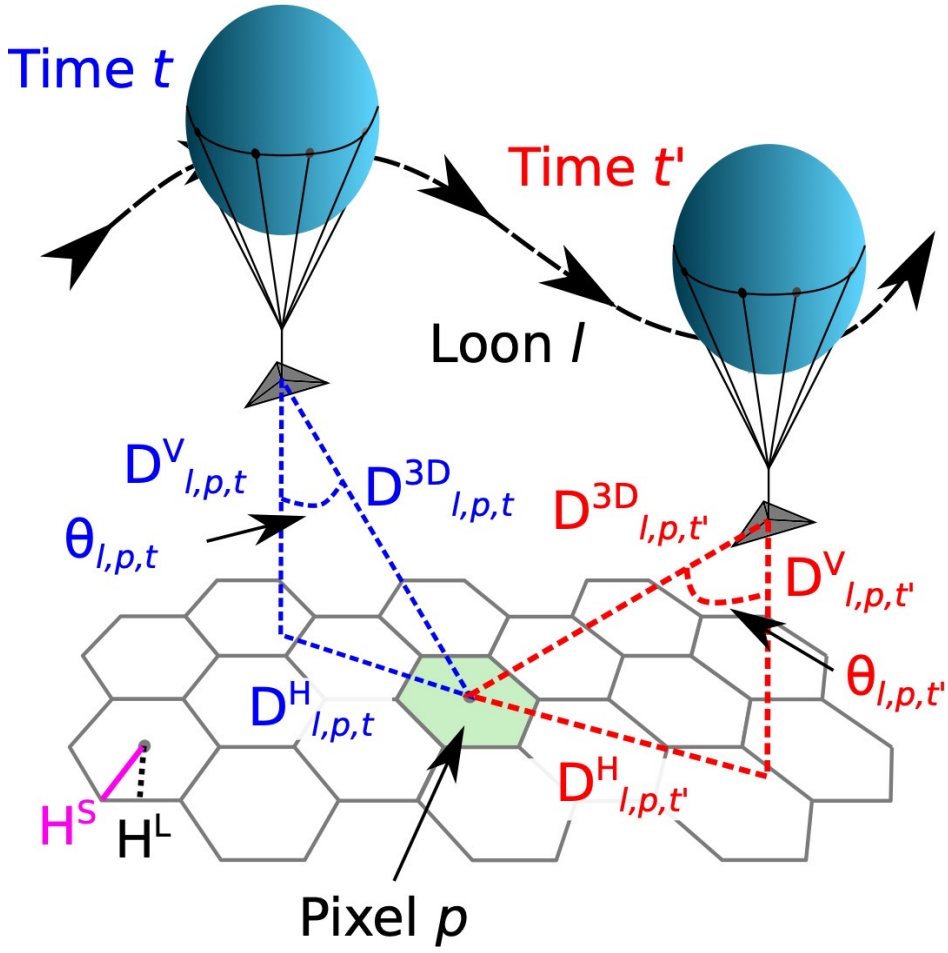
27 800 km^2



3) COMPUTING PERFORMANCE FIGURES

Methodology – “pixels”

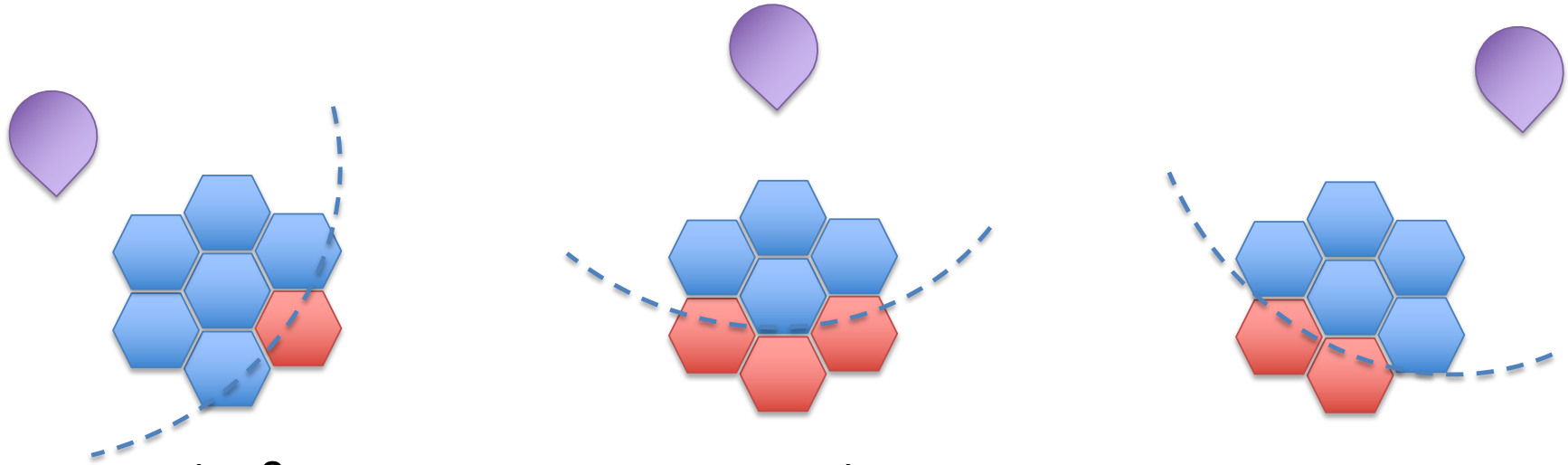
- Downlink
- Free-space loss
  - f: 800 MHz
  - P_{TX}: 37 dBm
  - G_{UE}: - 10 dBm
  - G_{TX}: [1]
- Coverage
  - Rsens: - 100 dBm



[1] S. Ananth et al. “System design of the physical layer for loon’s high-altitude platform,” EURASIP Journal on Wireless Communications and Networking, vol. 2019, no. 1, Jun. 2019.

Tessellation and discretization

- We (properly) discretize <u>space</u> and <u>time</u>



t = 0

6/7 ≈ 85%

t = 1’

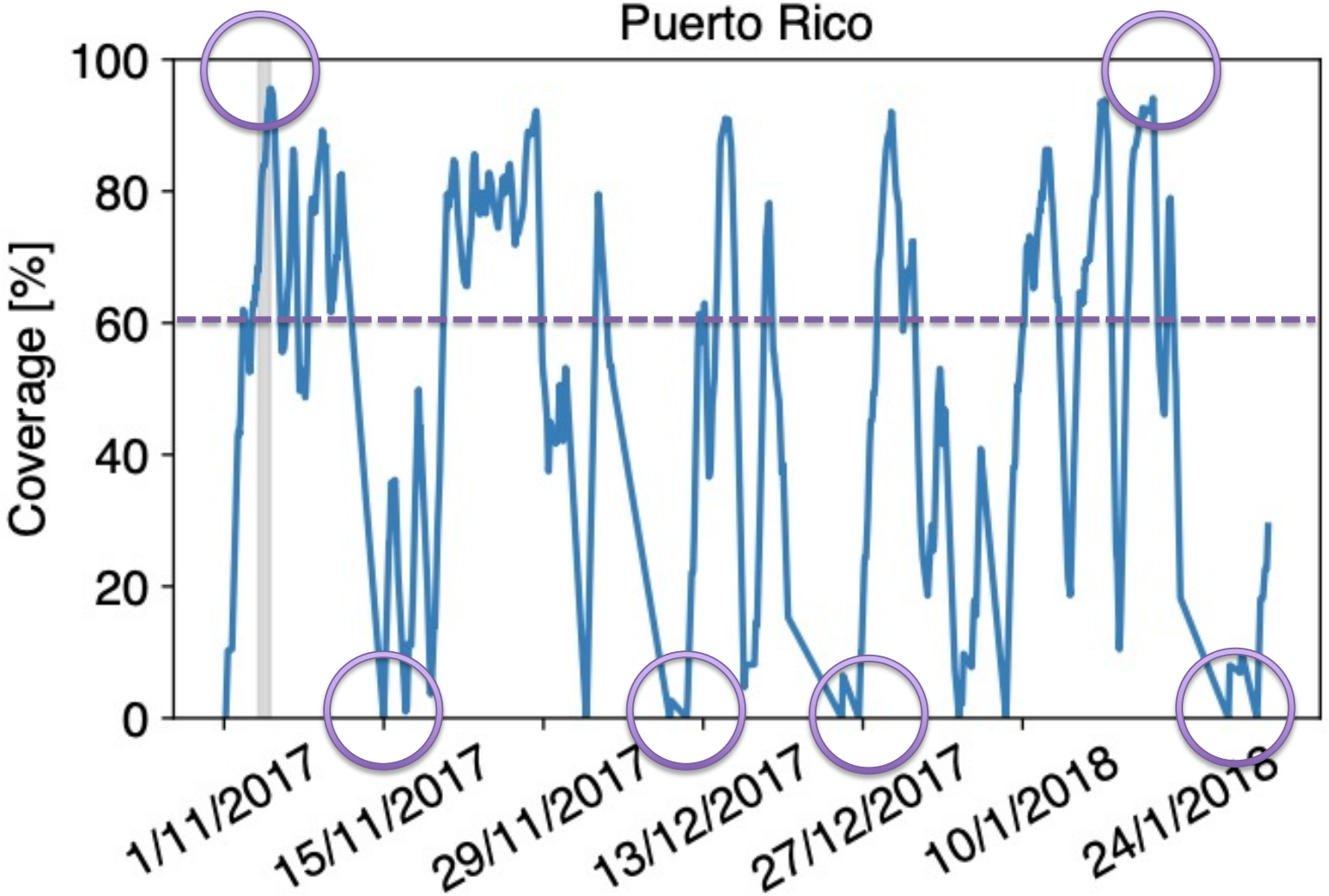
4/7 ≈ 57%

t = 2’

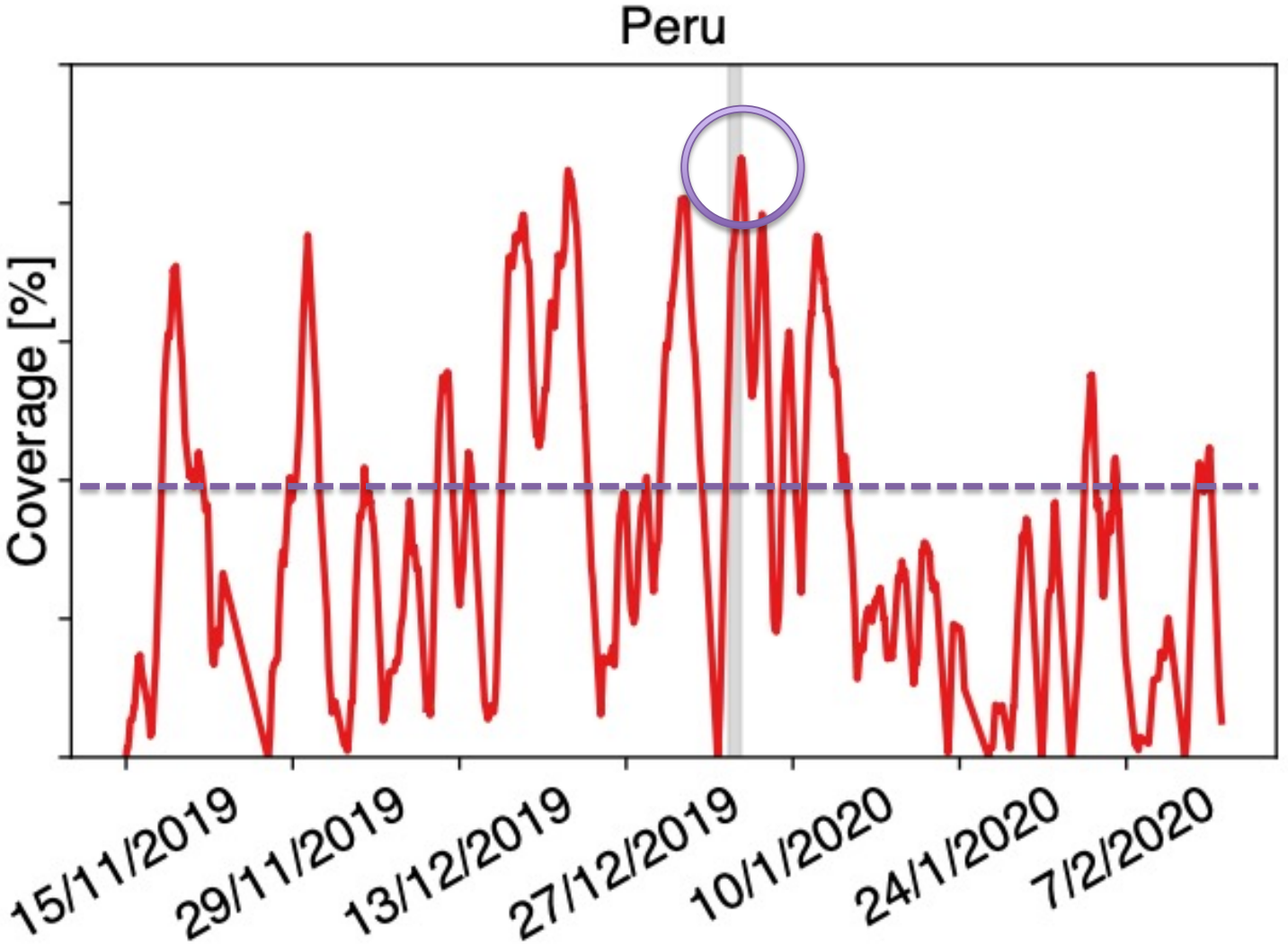
5/7 ≈ 71%

RESULTS:
DAILY COVERAGE

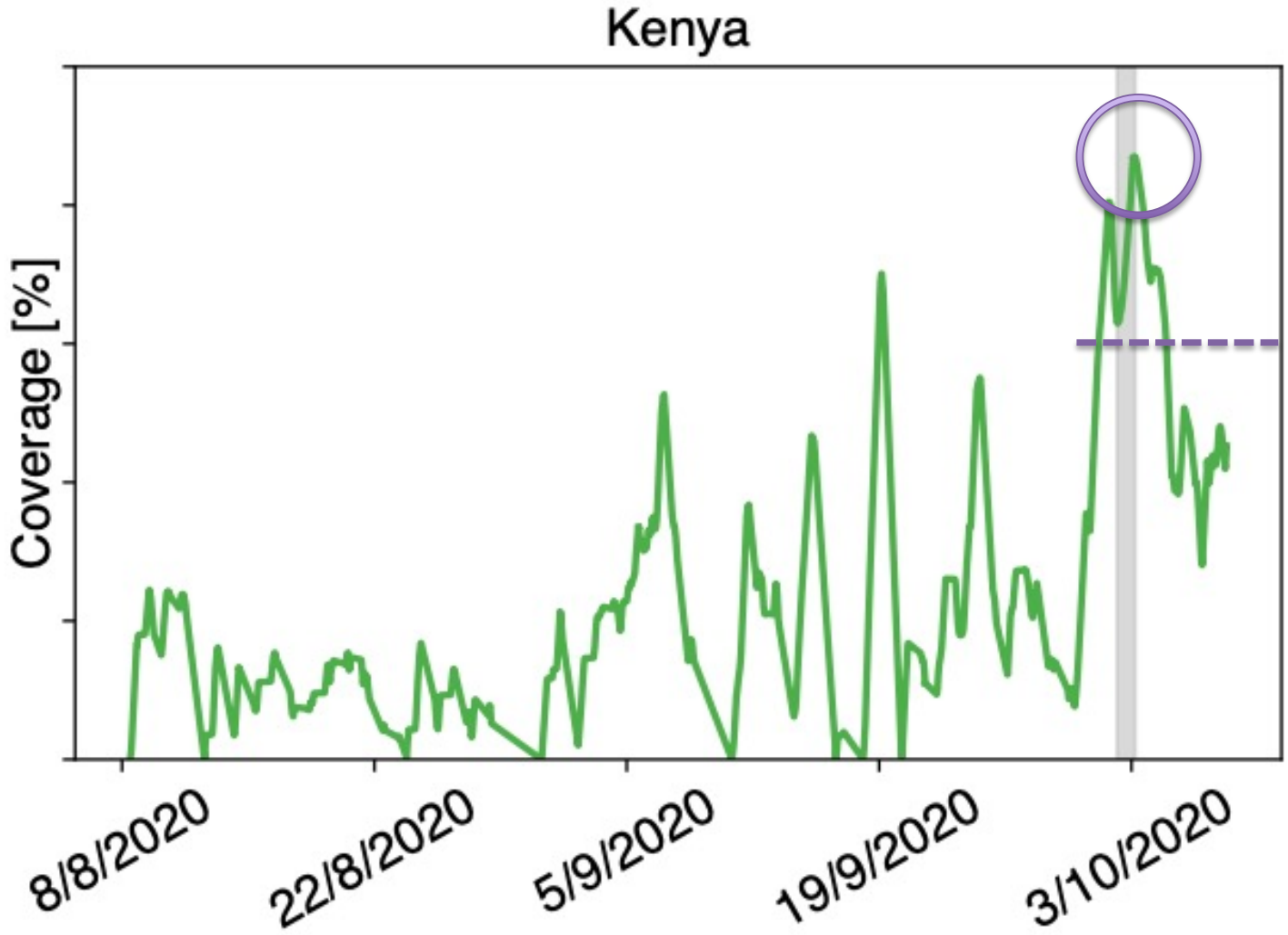
Puerto Rico: best 3 months



Perú


Peru
Coverage [%]
15/11/2019
29/11/2019
13/12/2019
27/12/2019
10/1/2020
24/1/2020
7/2/2020

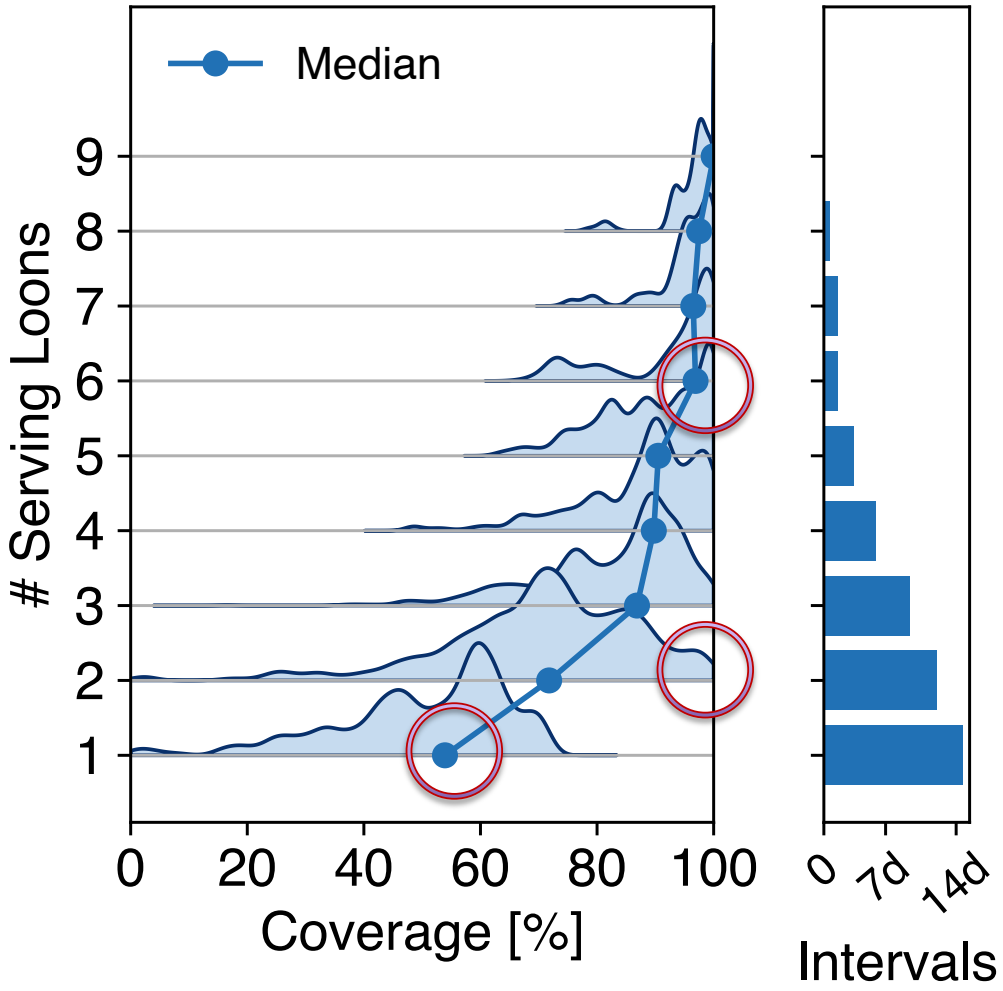
Kenya



COST OF COVERAGE

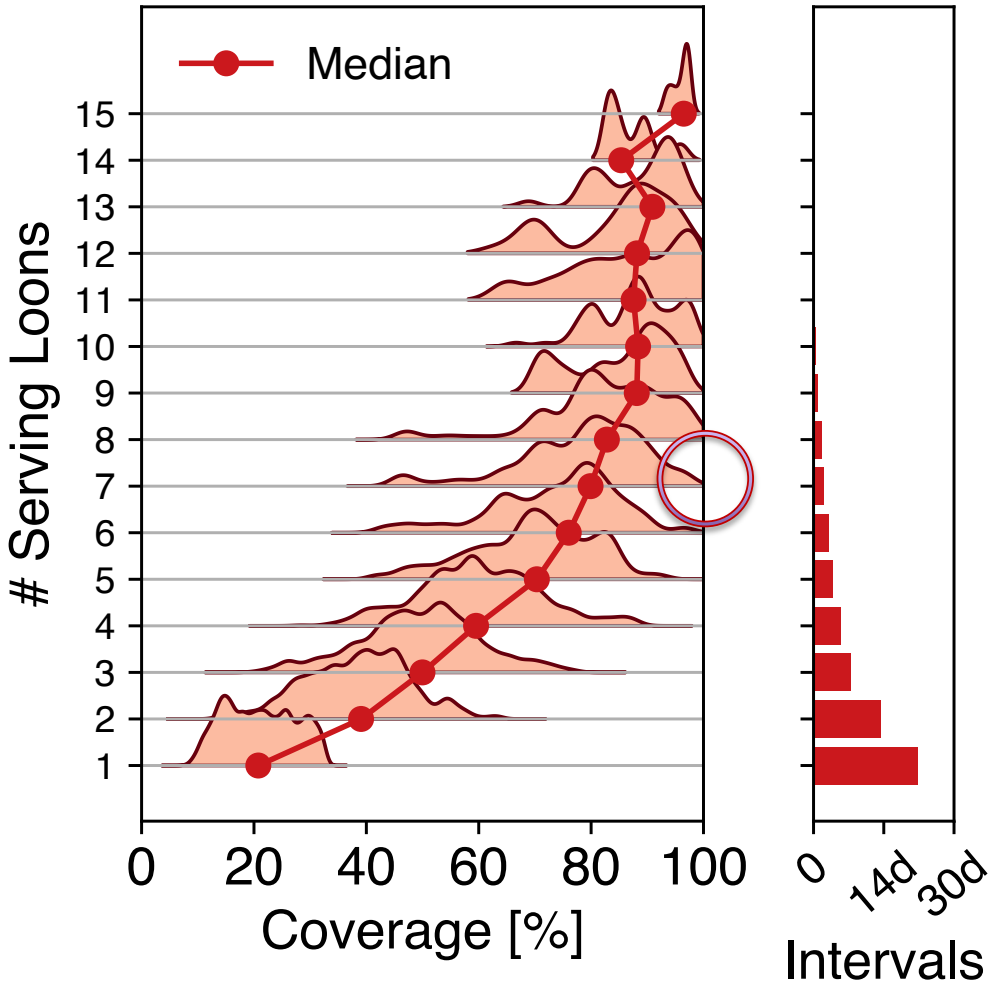
Puerto Rico

- Conditional density function of coverage
- With 2 loons
  - Median: 75%
- For ≥ 6 loons
  - Median > 90%



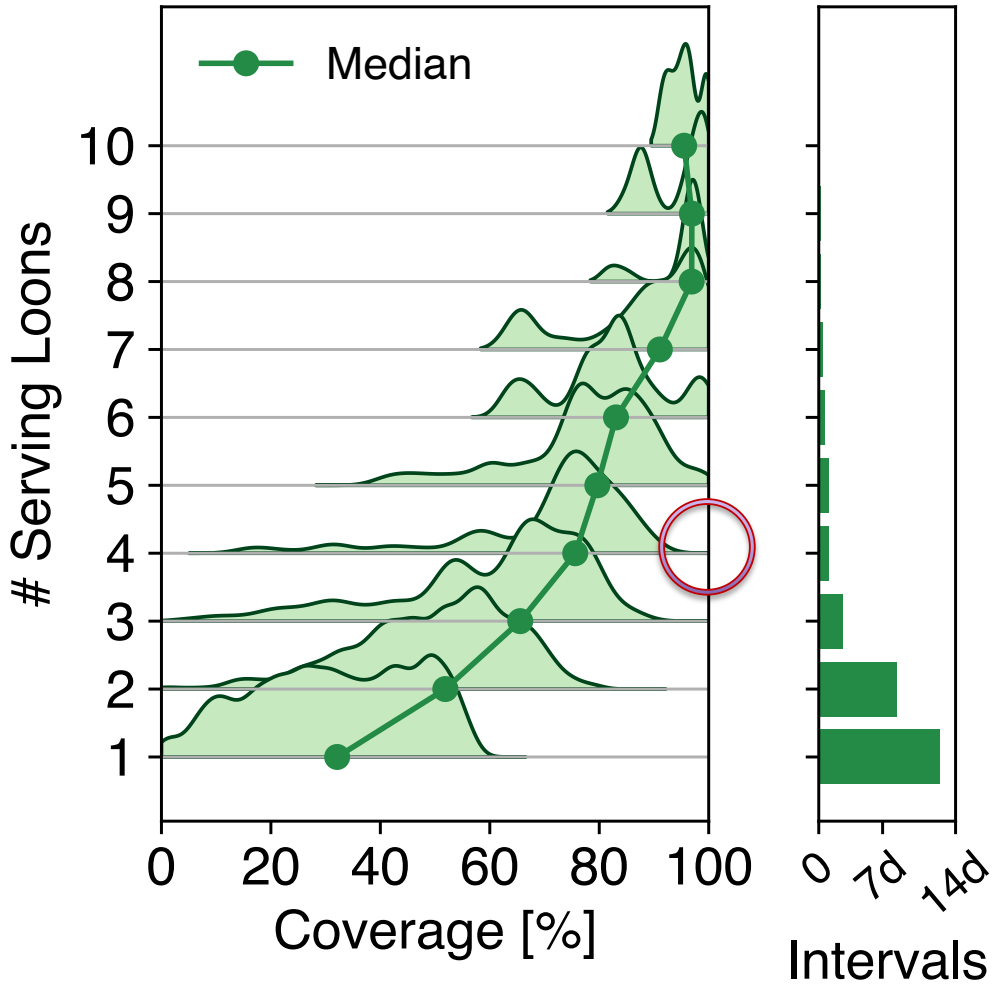
Perú

- Coverage only reaches 100% with ≥ 8 Loons
- Between 9 and 13: same median



Kenya

- Reaches 100% with 5 loons
- Extra loons improve coverage



ON THE BEST (AND WORST) SERVICE

Windowed maximal coverage

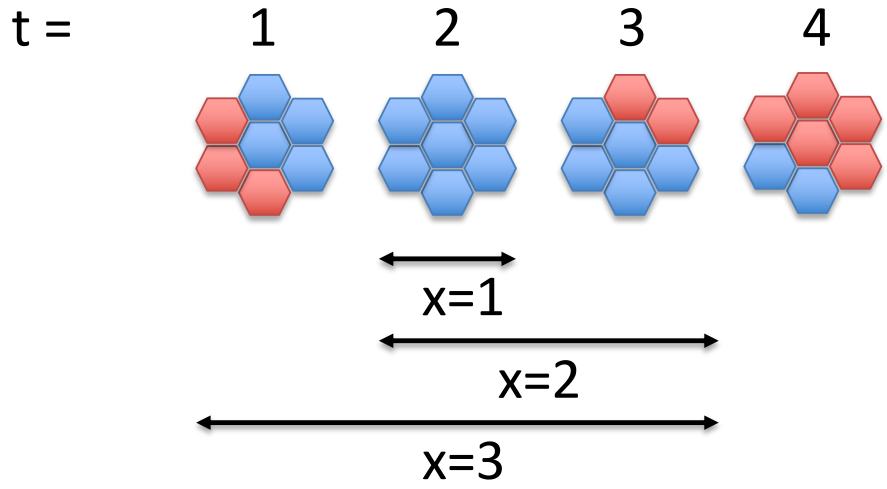
- Inspired by meaningful availability [1]
- Windowed max. coverage

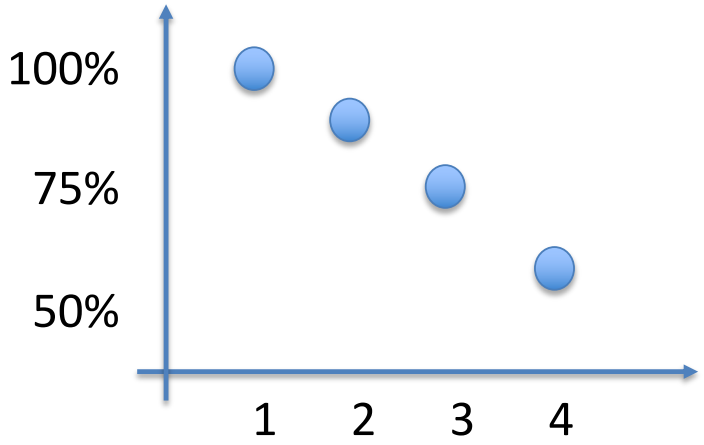
[1] T. Hauer et al. "Meaningful availability," in NSDI 20, Feb. 2020

$$W^{\text{C-MAX}}(x) \equiv \max_{T_1<t_1<t_2<T_2} \{N^{\text{COV}}_{t_1,t_2} \mid t_2 - t_1 = x\}$$

$N^{\text{COV}}_{t_1,t_2}$ is the avg. # pixels with coverage during [t_1,t_2]

- Idea: find the best avg. coverage during 'x'





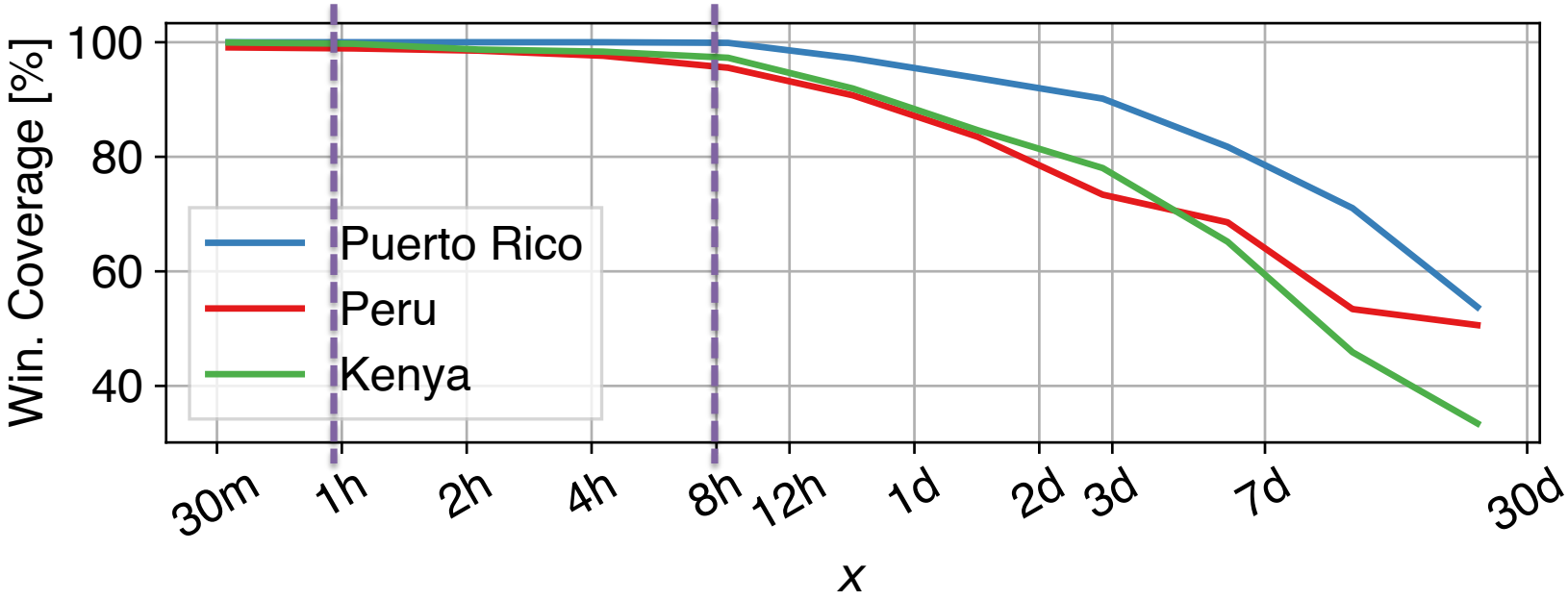
Windowed maximal coverage

- Inspired by meaningful availability [1]
- Windowed max. coverage

[1] T. Hauer et al. “Meaningful availability,” in NSDI 20, Feb. 2020

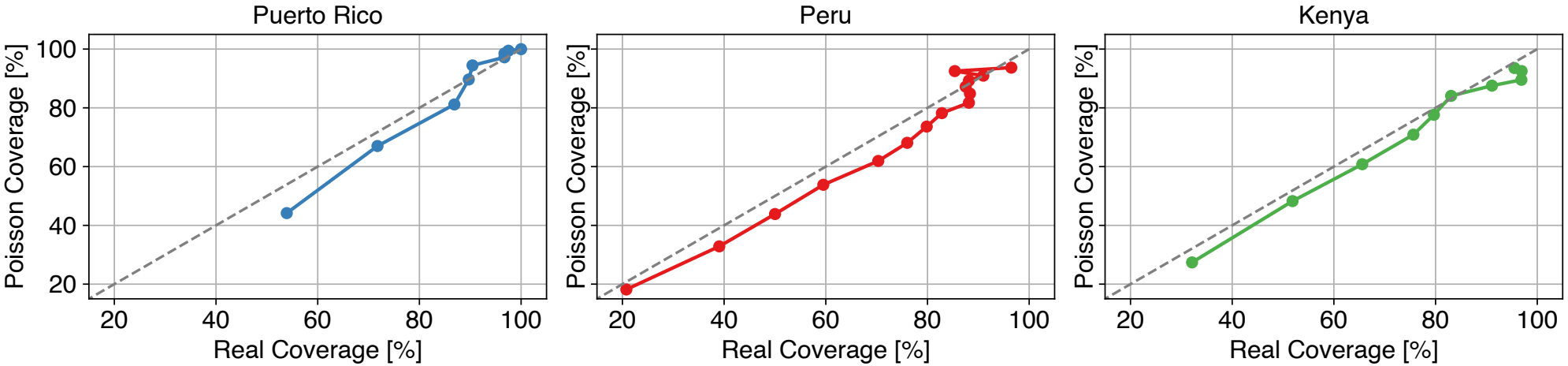
$$W^{\text{C-MAX}}(x) \equiv \max_{T_1<t_1<t_2<T_2} \{N^{\text{COV}}_{t_1,t_2} \mid t_2 - t_1 = x\}$$

$N^{\text{COV}}_{t_1,t_2}$ is the avg. # pixels with coverage during [t_1,t_2]



Comparison vs. random deployment

- Compute the median coverage with N loons
  - Real data vs.
  - Randomly deployed (“Poisson”)



SUMMARY

Summary

- Study Loon service under optimistic assumptions
  - Channel model, interference, inter-loon links
  - Areas and times with certain coverage
- It is a *better than nothing* delay tolerant service
  - Outage periods > hours
- Significant challenges
  - Diminishing returns of adding extra loons
    - A 3x over provision
  - Performance similar to a random deployment

Saying goodbye to Loon

- Jan 22, 2021: “we haven’t found a way to get the cost low enough to build a long-term, sustainable business” https://blog.x.company/loon-draft-c3fcebc11f3f
- SoftBank acquired approx. 200 Patents from Loon

  https://www.softbank.jp/en/corp/news/press/sbkk/2021/20210930_03/
- Loon compiled a book about the experience

  https://www.scribd.com/document/528613645/The-Loon-Library
- Alphabet has open-sourced the data of 70 million kms or so of flight, including GPS and sensor data

  https://zenodo.org/record/3763022

Balloons in the Sky: Unveiling the Characteristics and Trade-offs of the Google Loon Service

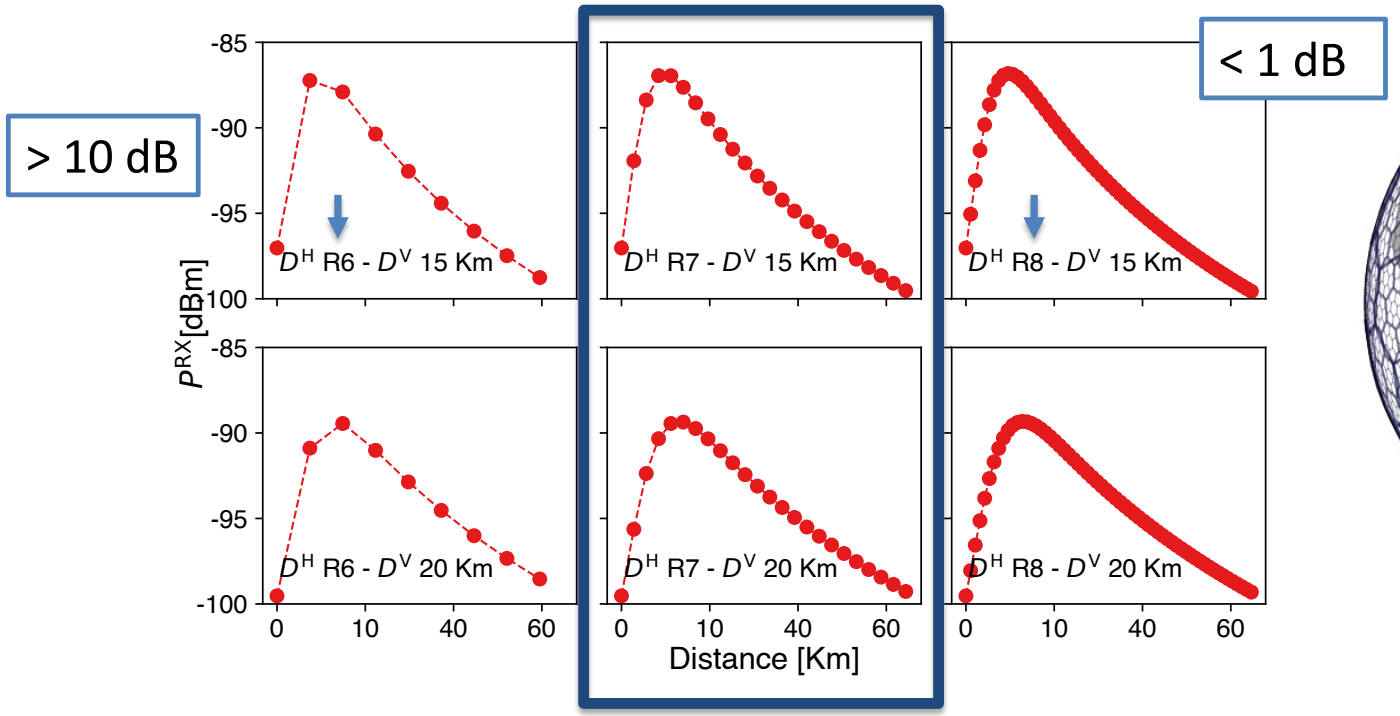
P. Serrano, M. Gramaglia, F. Mancini, L. Chiaraviglio, G. Bianchi, "Balloons in the Sky: Unveiling the Characteristics and Trade-offs of the Google Loon Service,"
IEEE Transactions on Mobile Computing, Dec. 2021
https://doi.org/10.1109/TMC.2021.3135976

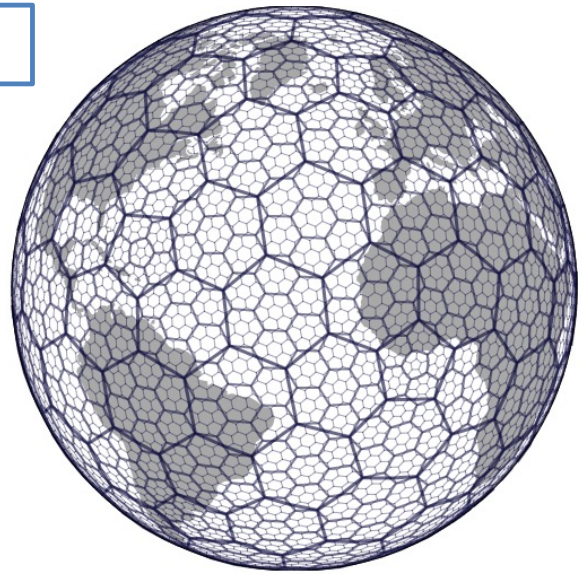
Pablo Serrano
Univ. Carlos III de Madrid (UC3M)
pablo@it.uc3m.es
http://www.it.uc3m.es/pablo/

ADDITIONAL RESULTS

Tessellation - granularity

- We use the H3 library to tessellate the regions
  - 16 resolutions: HS(0) = 1 279 km, HS(15) = 0,58 m

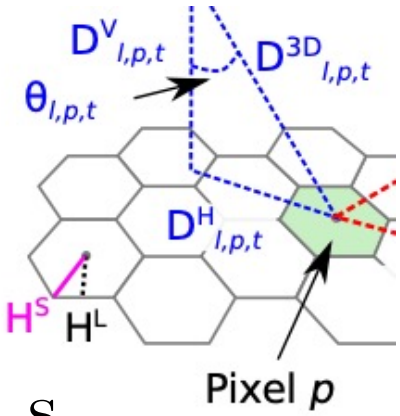




https://eng.uber.com/h3/

Time discretization

- Objetive: set a bound on Δt = t[n] - t[n-1]
- Aim: loon does not travel beyond $2H^S$ during Δt
- H^S: 1.4 km
- 99th percentile of speed: 100 km/h



$$\Delta_t \leq \frac{2 \cdot H^S}{V^{99\text{-PCT}}} = \frac{2.8\ [\text{km}]}{100\ [\text{km/h}]} \approx 1\ \text{min}\ 26\ \text{s}$$

- We set Δt = 1 min

About the lifespan

- Can operate for hundreds of days. Record: 312 days
  - HBAL703 launched from Puerto Rico in May, 2019
  - Test service for 3M / 7M in the Pacific / Landed in Mexico

https://medium.com/loon-for-all/312-days-in-the-stratosphere-5c50bd233ec5

Some issues – as of June 2014

- Google's Project Loon suffers accident as balloon takes out power lines
  - "Google has no way of ensuring its balloons won't wreak havoc once they're closer to the ground"

https://www.theverge.com/2014/6/3/5777182/google-project-loon-balloon-takes-out-power-lines

- Google Loon Wi-Fi balloon creates panic in New Zealand
  - "Rescue helicopter dispatched for what was thought to be a crashing plane"

https://www.theverge.com/2014/6/20/5826988/google-loon-balloon-crash-new-zealand

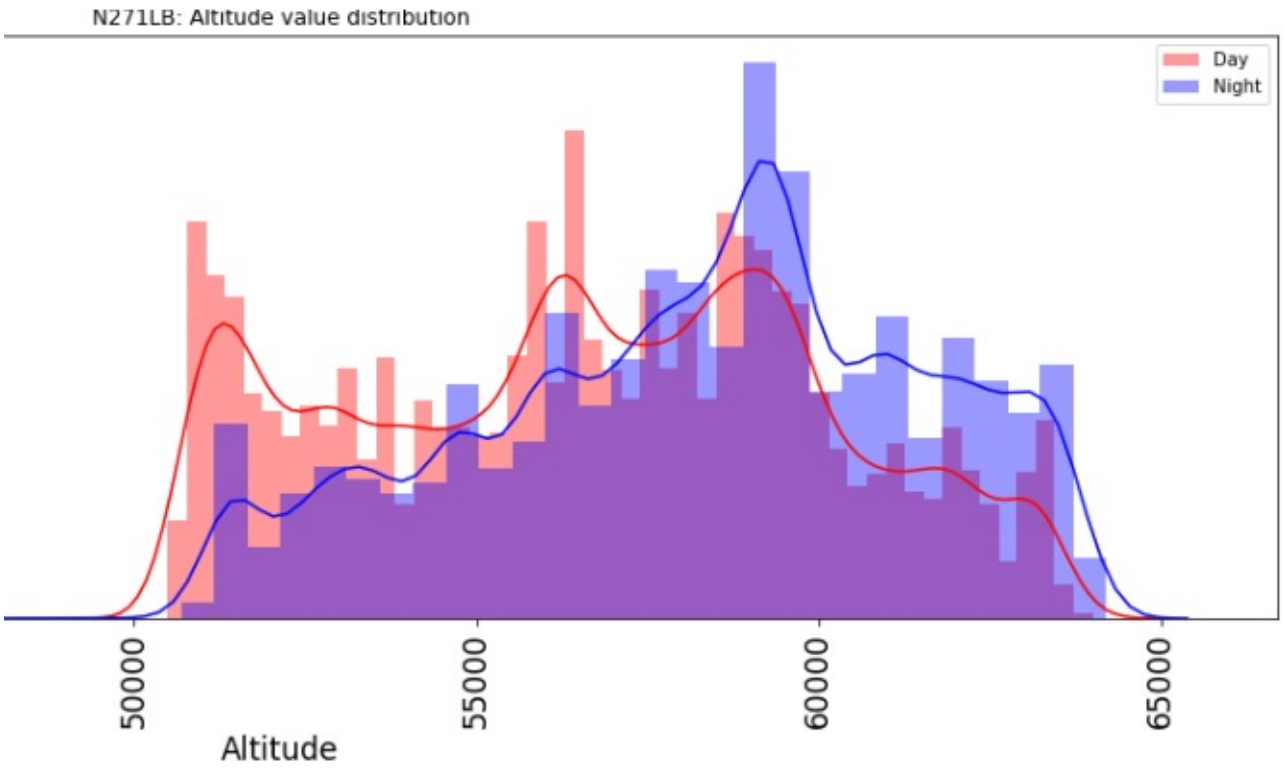
Balloons sightings

- “A Brief History of People Thinking Google's Loon Balloons Are UFOs”

https://gizmodo.com/a-brief-history-of-people-thinking-googles-loon-balloon-1661296616

https://www.bbc.com/news/world-latin-america-39265813

Day & Night



Cool to hear you're thinking about Loon!

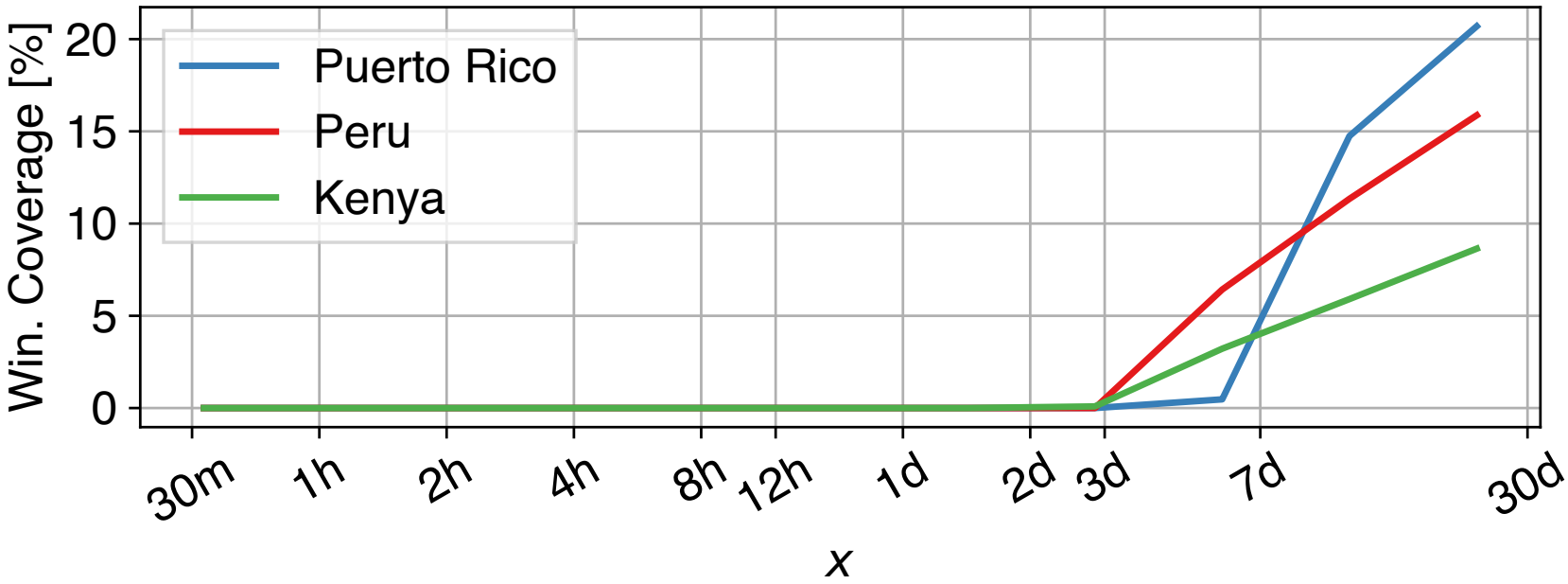
This distribution is correct and usual. Our navigation system determines the best altitudes to fly and it's different day to night when there are different superpressure and power characteristics.

Obviously I can't reveal any secrets of how our system has learned to navigate, but I can confirm the behavior you observe is expected.

Windowed minimal coverage

- Windowed min. coverage

$$W^{\text{C-MIN}}(x) \equiv \min_{T_1<t_1<t_2<T_2} \{N^{\text{COV}}_{t_1,t_2} \mid t_2 - t_1 = x\}$$



Outage time distribution

- Collect all downtimes per pixel (hexagon)
- Compute the median (per pixel)